Microbiology of the Frankfurter Process: Salmonella and Natural Aerobic Flora

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Salmonella senftenberg 775W added to frankfurter emulsion was killed during normal processing in the smoke house when internal product temperature was 71.1 C (160 F) or above. The thermal destruction point of *S. senftenberg* 775W in frankfurters (temperature at which no viable cells were detected) was a function of the length of time of the process rather than of the starting number of cells. Heating of frankfurters to 73.9 C (165 F) substantially reduced the total non-salmonella count. For total non-salmonella bacterial flora and salmonella, relatively little thermal destruction occurred below 43.3 C (110 F). The heating step can bring about a 7-log cycle decrease (10^8 to 10^1/g) of bacteria present in the raw emulsion. The flora of this high-bacteriological-count raw emulsion was predominantly gram-negative rods. Variation in the number of bacteria (both total and salmonella) surviving at various temperatures during processing was attributed to slight variations in the temperature pattern of the smoke house during its operation. An integration process was devised which allowed calculation of exposure to temperatures above 110 F (43.3 C) on the basis of degree-minutes. Plots of degree-minutes versus log of surviving bacteria were linear. The salmonella plot had a greater slope than that of the total non-salmonella flora, indicating that salmonellae are more heat sensitive than the bacterial population as a whole. The predominant bacteria surviving the heating step were micrococci. These micrococci were able to increase in number in or on the frankfurters during storage at 5 C.

Although salmonellae are often found on the raw meats used to manufacture processed meat products (14, 15) and in fresh pork sausage (7, 12), they are rarely found in the processed product (14, 15). Apparently salmonellae do not survive the heat processing given these products. Few data are available which detail the effects of actual processing conditions on the destruction or survival of salmonellae or of the aerobic (non-salmonella) bacterial flora in processed meat products. Furthermore, information about the flora that survive heat processing could be useful in predicting the shelf life of the products as well as the adequacy of the heating step of the process. Therefore, we investigated the thermal destruction of: (i) the total (non-salmonellae) bacterial flora, and (ii) salmonellae during the heating step of frankfurter processing.

Salmonella senftenberg 775W, the most heat-resistant strain known (11, 16), was chosen for the main part of this study. We thought that if *S. senftenberg* 775W were killed during the normal heating step, all other serotypes which might be present in raw frankfurters also would be killed. The types of bacteria surviving the various temperatures during frankfurter processing were studied in terms of their potentials for spoilage.

MATERIALS AND METHODS

Meat and preparation of frankfurters. Lean beef, lean pork, and pork fat were obtained from a local supplier. Each was ground once through a ¾-inch (ca. 1.9 cm) plate; representative samples of each were analyzed for moisture, fat, and protein by standard procedures (1). The rest of the ground material was packed in appropriate size portions in Cry-O-Vac bags and stored at −17.8 C. Frozen lean meats and fat were removed from the freezer the day before processing and partially thawed at 12.8 C. The partially thawed meats and fat were ground once through a 7/16-inch (ca. 0.26 cm) plate. Based on the compositional analyses of the meats and fat, a meat-fat formula was calculated to provide finished frankfurters containing 30% fat and no more than 10% added moisture. A typical batch contained 5.1 kg of lean beef, 3.2 kg of lean pork, and 4.03 kg of pork fat. Each batch was chopped with 4.01 kg of ice and curing agents at levels equivalent to 0.154 g of $NaNO_2$, 1.265 g of $NaNO_3$,

and 0.529 g of sodium ascorbate per kg of meat and fat. All batches contained (per kilogram of meat and fat): 19.8 g of sugar, 25.1 g of NaCl, and 5.29 g of commercial spice mixture.

Emulsions were prepared in a Koch model 25 high-speed Schnellkutter; all components were added to the cutter bowl, with the curing agents were added as a solution in 100 ml of water. The mixture was chopped until the temperature of the emulsion was 15.6 C. The emulsion was stuffed in 23-mm No-Jax casings (Union Carbide) and linked. The linked frankfurters were cooked in an air-conditioned smoke house operated according to the following schedule: 10 min at 54.4 C dry bulb (DB), 30 min at 62.8 C DB and 57.2 C wet bulb (WB), 45 min at 73.9 DB and 60 C WB, and finally 87.8 C DB and 76.7 C WB until the internal temperature was 73.9 C (71.1 C for the salmonella experiments). Frankfurter temperature was monitored continuously during heating by a thermocouple inserted into a raw frankfurter and was recorded by an Electronik model 16 recorder (Honeywell).

For experiments where frankfurters heated to different internal temperatures were to be analyzed bacteriologically, short strands of linked frankfurters were prepared and then removed from the smoke house as the product reached selected temperatures. These frankfurters were then immersed in an ice-water slurry to cool rapidly.

Microbiology: general. A 50-g amount of raw emulsion or frankfurter cooked to specific temperatures was aseptically removed from the casing and blended with 200 ml of 0.1% peptone water for 1 min at high speed in a Waring blender. Appropriate dilutions were pour-plated with tryptic soy agar (Difco); 0.1% peptone water was used as diluent. Colonies were counted after 4 days of incubation at 25 C. Gram stains of the various colony types were examined with a microscope; the catalase test was also run on these same colonies. The term total flora refers to the total, aerobic, non-salmonella flora counted by this procedure.

Preparation of salmonellae-containing frankfurters. Two methods were developed for inoculating the raw emulsion with salmonellae. In the first, the bag method, raw emulsion was added to a plastic bag and an appropriate number of salmonellae suspended in green food dye-peptone water were added and thoroughly mixed with the emulsion. In the second, the cutter method, the diluted salmonellae in green food dye were added directly to the Schnellkutter bowl before the emulsion was formed; thus, the organism became an integral part of the emulsion network. The green food dye was used as a tracer to ensure uniform mixing of the contaminant and as a deterrent to unauthorized consumption of the finished product.

Microbiology: salmonella. Raw, salmonella-containing emulsions or salmonella-contaminated frankfurters cooked to specific internal temperatures (120 g) were aseptically removed from the casings and blended with a mixture of 400 ml of selenite cystine broth (Difco) and 2.4 ml of Tergitol 7 for 3 min at high speed in a Waring blender. Both the total direct and most probable number (MPN) salmonella counts (three tubes, three dilutions) were made from this blended emulsion (BE). For the direct viable salmonella count, 0.1 ml of the BE, or a dilution thereof, was spread on the surface of brilliant green agar plates (BGA; Difco), and typical magenta colonies were counted after 24 h at 37 C. Colonies on BGA were routinely subjected to serological analysis; *Proteus* spp. or other bacteria which might give colonies similar in appearance to salmonella were never observed. For the MPN salmonella counts, 43.1-, 43.1-, and 4.31-g portions (equivalent to 100, 10, and 1 g, respectively, of original frankfurter emulsion) of BE were removed, placed in appropriate containers, and incubated for 24 h at 37 C. Samples from these enrichments were then streaked onto BGA plates and incubated for 24 h at 37 C. Typical magenta colonies were picked and inoculated into lysine-iron agar (Difco); the salmonella were finally confirmed by serology with O antisera. The MPN per gram was then calculated by use of an MPN table. The direct salmonella method was used for frankfurters and raw emulsion containing relatively high levels of salmonellae, whereas the MPN method was used when low levels of salmonellae were anticipated.

S. senftenberg 775W and *S. dublin* were from the laboratory stock collection and were grown for 24 h in tryptic soy broth (Difco) incubated at 37 C. A 0.5-ml volume of culture was added to 100 ml of 0.1% peptone water containing 5 ml of a green food dye (see above); 10 ml of this diluted culture-food dye mixture was used to inoculate 1 kg of raw emulsion. This dilution gave an approximate count between 10^4 and 10^5 organisms per gram.

Processing equipment was cleaned and sanitized as follows. Solid, raw emulsion was removed, placed in a container, and autoclaved. The equipment then was soaked and washed in a solution of Chloroterg cleaner (Oakite), followed by rinsing and steam treatment. Throughout the processing operation, laboratory personnel wore disposable plastic gloves, aprons, and lab coats which were autoclaved after use. The green food dye in the emulsion also facilitated clean-up by permitting location of any contaminated emulsion.

RESULTS

The importance of thermal destruction of bacteria during frankfurter processing cannot be overemphasized. Because of this importance, the bacteriology of the process was studied in detail with regard to both total flora and to salmonella. Figure 1a shows the variation in temperature response of frankfurters during four experiments (I to IV) using the same smoke house schedules. The causes of the difference might be external conditions of temperature, humidity, etc., or just the normal variation of the smoke house; these could not be controlled more precisely under our experimental conditions.

Figure 1b gives survivor curves for total flora in products heated to temperatures in Fig. 1a.

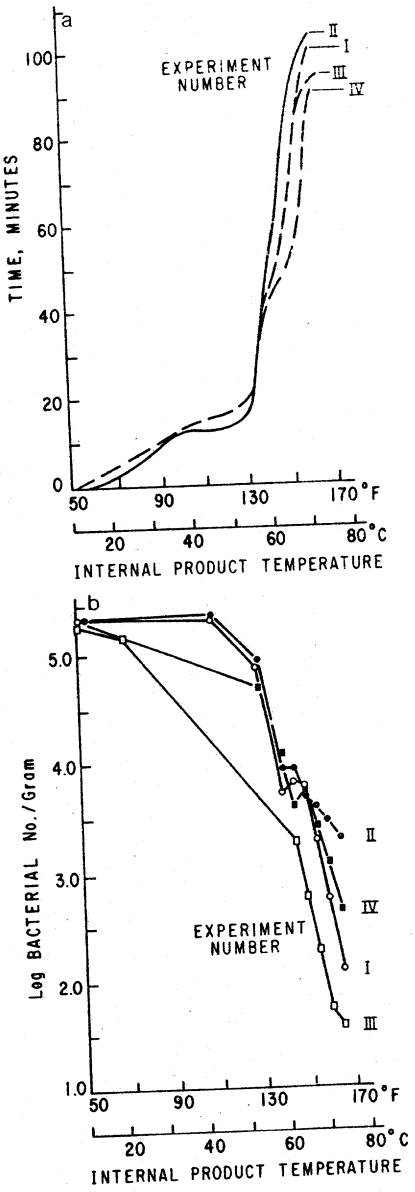

FIG. 1. *Influence of processing conditions on the total (non-salmonella) bacterial count of frankfurters processed to different internal temperatures. (a) Plot of internal product temperature versus time for four different experiments (I to IV) employing the same smoke house heating schedule. (b) Plot of log of viable bacterial number per gram versus temperature for the same four experiments (I to IV) given in (a).*

Although all batches of frankfurters were prepared from the same starting meats that had been frozen, and the frankfurters in the four experiments were heated according to the same smoke house schedule, viable cell counts varied considerably, especially the final counts. In experiment III, the surviving bacteria were gram-positive, catalase-positive, spore-forming rods (bacilli), whereas in the other three experiments the survivors were gram-positive, catalase-positive cocci (micrococci). Among the three experiments, the number of micrococci surviving also varied.

In general, most of the killing occurred after the product temperature reached 43.3 C (110 F). At the beginning of heating, the predominant flora were gram-negative rods with some micrococci; most of the gram-negative rods were destroyed by the time the product temperature reached 60 C. Above 60 C, only micrococci were found.

Data from three experiments with *S. senftenberg* 775W are presented. Although the salmonellae-containing frankfurters were processed according to the same smoke house schedule, considerable variation in the time required to reach various internal temperatures was observed. These smoke house runs were conveniently designated as slow-heating (experiment VII), medium-heating (experiment V), and fast-heating (experiment VI) houses. Figure 2a shows viable salmonella and product temperature plots for experiment V; in this experiment, salmonellae were added to the emulsion by the bag method. No viable salmonellae were found in products heated to 68.3 C and above; relatively little thermal destruction occurred before 57.2 C.

Figure 2b shows viable salmonellae and product temperatures for experiment VI; in this experiment, salmonellae were added to the emulsion by the bag and cutter methods. Viable salmonellae are detected in the product heated to 68.3 C (0.018 organisms per g with the bag method and 0.056 organisms per g with the cutter method). The apparent discrepancy between the salmonella thermal death point in experiments V and VI may be explained by their respective heating curves. In experiment V, the product took 35 min to go from 65.6 to 68.3 C, whereas in experiment VI the product took only 4 min. Thus, in experiment V, the product was in this lethal temperature increment longer, and complete destruction occurred.

Although similar numbers of salmonellae were added in experiment VI, there was a log cycle difference in the number of salmonella found at zero time between emulsions inoculated by the bag and by the cutter method. Possibly the high shearing forces of the cutter destroyed some salmonellae. We had thought that incorporation of the salmonellae into the

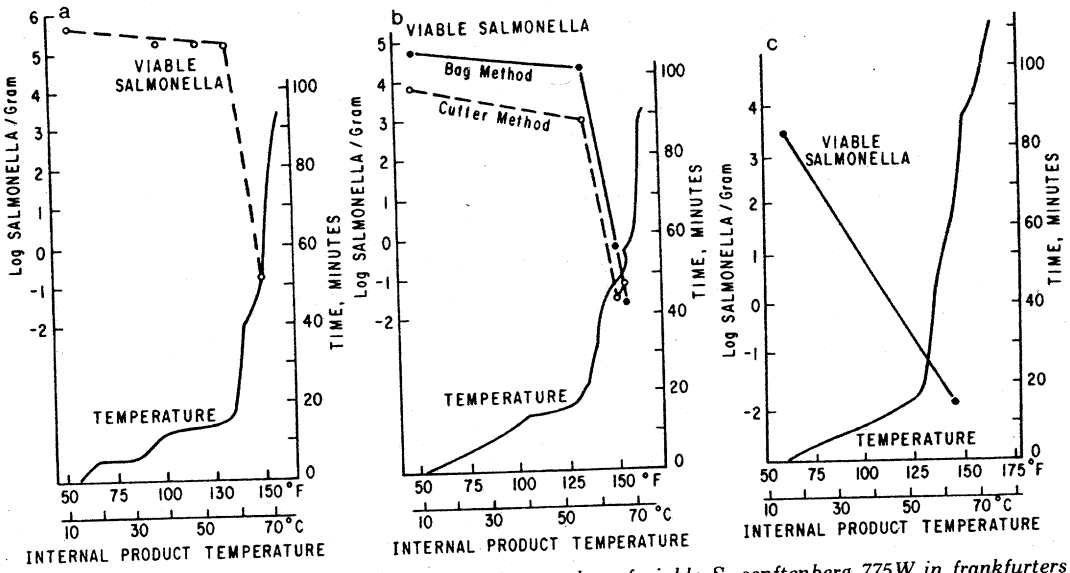

FIG. 2. *Influence of processing conditions on the number of viable S. senftenberg 775W in frankfurters processed to different internal temperatures. (a) Expt V—medium-heating house; salmonella added by bag method. (b) Expt VI—fast-heating house; salmonella added by bag and cutter methods. (c) Expt VII—slow-heating house; salmonella added by bag method.*

emulsion might protect the organism during heating. However, after the initial kill during incorporation into the emulsion, the curves were essentially parallel. The apparent discrepancy at 68.3 C probably reflects the difficulties associated with quantitating small numbers of salmonellae. The cutter method simulates commercial operations.

Figure 2c shows viable salmonellae and product temperatures for experiment VII. The salmonellae were incorporated by the bag method. In this experiment, no viable salmonellae were detected in products heated to 65.6 C. Comparison of the heating curve with those of experiments V and VI indicates that, in experiment VII, the product was heated more slowly than in the previous two experiments. The differences in times required to reach various internal temperatures and the viable counts at these temperatures are presented in Table 1. Some of the differences in the counts may be attributed to differences in the starting counts. However, examination of the time required for the product to reach the temperatures indicated that, in experiment VII, the product reached temperature slowly, whereas in experiment VI the product reached temperature rapidly, and experiment V was intermediate. The viable salmonella counts are reflected in the different times required to reach temperature (Table 1). In the "slowest experiment," VII, no viable salmonella were detected in product heated to 65.6 C, whereas in the fastest experiment, V, the last temperature at which viable salmonellae were detected was 68.3 C.

The above data on the thermal destruction of total flora and added salmonellae further support what is already known: thermal destruction of bacteria is a time-temperature function. Therefore, a method was sought which would combine the lethal effects of time and temperature on bacterial destruction during frankfurter processing. Since Fig. 1 and 2 indicate little, if any, thermal destruction below 110 F (43.3 C), only temperatures above this were considered. The method devised was an integration process accomplished by tracing the area of the recorder chart within the lines formed by the reference temperature (ice bath) and the product temperature. For the time parameters, the base lines were from the time the product temperature reached 110 F (43.3 C) (taken as zero) and up to the time the product took to reach various temperatures. The weights (in grams) of the areas of paper bound by these parameters were converted into arbitrary units which were plotted against log survivors for total flora and for salmonella; 125 degree-minutes equal 0.03288 units (grams). (Fig. 3). Best-fit straight lines and correlation coefficients were calculated by linear regression. The correlation coefficient was −0.77 for total flora, based on collective data from the four separate experiments, and was −0.95 for salmonellae, based on collective

TABLE 1. *Influence of time to reach various internal temperatures on the destruction of S. senftenberg 775W in frankfurter emulsion*[a]

Temperature		Viable salmonella count (per g)	Time to reach temperature (min)
C	F		
Expt VII: slow-heating house			
18.3	65	2.2×10^3	0
62.8	145	0.015	66
65.6	150	0	88
68.3	155	0	92
71.1	160	0	102
Expt V: medium-heating house			
12.8	55	5.1×10^5	0
37.8	100	1.8×10^5	12
48.9	120	1.8×10^5	13
57.2	135	1.49×10^5	18
65.6	150	0.24	52
68.3	155	0	87
71.1	160	0	93
Expt VI: fast-heating house			
10	50	5.5×10^4	0
57.2	135	1.84×10^4	22
65.6	150	0.46	48
68.3	155	0.018	54
71.1	160	0	64

[a] All salmonella were added by the bag method.

data from the three separate experiments. Furthermore, the slope of the lines indicated that the total flora (slope = −0.89) are much more heat resistant than the salmonellae (slope = −5.45). This was not unexpected if one considers that: (i) heat completely destroyed the salmonellae, and (ii) the total flora represented a mixture of bacteria with different heat resistances (gram-negative rods and gram-positive cocci with a few gram-positive spore-forming rods) and that the normal frankfurter heating process destroys completely only the gram-negative rods (organisms of relatively low heat resistance).

The data employed to prepare Fig. 3 and also Fig. 5 were subjected to further statistical analysis using the least-squares method. In all instances, the second-degree, or quadratic, component was not significant. This provides additional support for the validity of our integration method for computing lethality, and thus a linear relationship between log number and degree-minutes is the valid one.

The bacterial contributions of the various components of frankfurter emulsion to the bacteriological load of raw emulsion were determined (Table 2). The count for finished raw emulsion was lower than the sum of the bacterial load contributed by the components. The count of finished raw emulsion was 7.0×10^4 organisms per g, whereas the load contributed by the components in the proportion found in

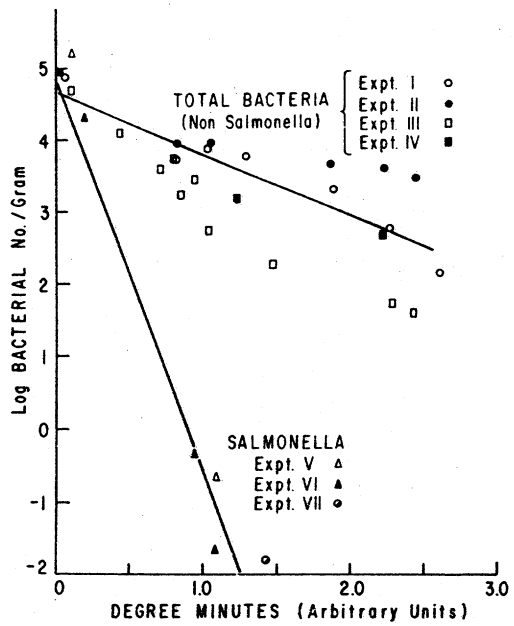

FIG. 3. *Log of bacterial number versus total heat treatment (degree-minutes—in arbitrary units) for total (non-salmonella) bacteria and for S. senftenberg 775W in frankfurters.*

TABLE 2. *Bacteriological examination of the components of frankfurter emulsion prepared in our pilot plant*

Component	No. of organisms (per g)	Predominant flora
Beef	1.2×10^5	Gram-negative rods
Pork	2.6×10^5	Gram-positive rods and micrococci
Pork fat	6.0×10^4	Gram-positive rods and micrococci
Ice	<10	
Salt	<5	
Sugar	5	Gram-positive, spore-forming rod
Commercial spices	<5	
Finished emulsion	7.0×10^4	Gram-negative rods and micrococci
Stuffed emulsion	6.0×10^4	Gram-negative rods and micrococci
Frankfurter processed to 73.9 C	9.6×10^2	Micrococci

the emulsion should yield a count of 1.0×10^5/g. Apparently some bacteria were killed in the Schnellkutter during emulsion formation. This decrease in total was less than the approximately 1-log cycle decrease of salmonellae in the Schnellkutter.

To compare the bacteriological quality of our finished emulsion and finished frankfurters with those produced commercially, a count was made on a sample of commercial frankfurter emulsion. It had a count of 3.2×10^5 organisms per g and contained micrococci and gram-negative rods. We then processed frankfurters from this emulsion and made a bacteriological count of them. The major difference between frankfurters we processed and those processed commercially appeared to be the surviving flora. The commercially processed frankfurters had a count of 2.6×10^2 organisms per g and contained gram-positive, sporeforming rods; in contrast, ours had a count of 1.2×10^2/g and contained micrococci and some gram-positive rods (nonsporeforming).

Data from our own and commercially processed emulsions and presented by Heiszler et al. (8) indicate that only 2- to 3-log cycles of killing occur during normal frankfurter processing, e.g., the counts decrease from 10^5 organisms per g in the raw emulsion to 10^2/g in the finished frankfurter. Whether this represents a dependence upon the flora present or simply the ability of the process to kill only this number of bacteria was investigated. After partial thawing, beef, pork, and pork fat were ground through a 1/16-inch plate and then stored for 6 days at 5 C. Bacteriological counts made during this aging period indicated that at 6 days the counts were still increasing. These aged meats had a marked putrid odor and could not be employed to manufacture frankfurters in any plant under federal inspection (Mandatory Meat Inspection, U.S. Code of Federal Regulations, Title 9, revised 1973, p. 337-338). These aged meats and fat then were made into frankfurters and processed in the smoke house. Samples were removed as various internal temperatures were reached during the heating; these samples were then analyzed bacteriologically (Fig. 4 and 5). Because of the extremely poor quality of the starting meats, these frankfurters were not tasted.

Although the starting count of the raw emulsion was 3-log cycles higher than in any previous experiment, the bacterial count of the finished frankfurters processed to 73.9 C was 3.7×10^1/g (Fig. 4). Thus, the process is capable of destroying large numbers of bacteria. A plot of degree-

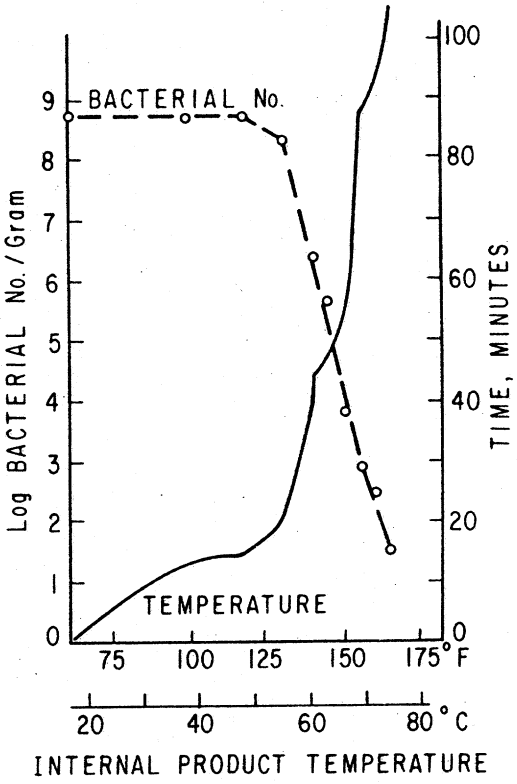

FIG. 4. *Influence of processing conditions on the total bacterial count in frankfurters made from high-bacteriological-count raw materials.*

minutes versus log survivors is given in Fig. 5. Examination of Gram stains of bacteria surviving various temperatures showed that, at temperatures up to 62.8 C, gram-negative rods and micrococci were present; at 65.6 C and above, only micrococci were found. Linear regression analysis of the data gave a correlation coefficient of -0.9660 and a slope of -2.55.

Although the added salmonellae were killed by the heating step of frankfurter processing (Table 1), mishandling of the raw emulsion before processing might allow proliferation of the salmonellae to such high levels that they might not all be killed by the heating step. To investigate this possibility, we inoculated raw emulsion with salmonellae and incubated it at different temperatures. Viable salmonellae were counted after 24 h. In most instances, there was neither appreciable growth nor death (Table 3). The presence or absence of nitrite seemed to have no effect. In contrast to salmonellae, the total flora of raw emulsion increased markedly during incubation at 20 and 35 C (Table 3).

Storage studies. The total count of finished

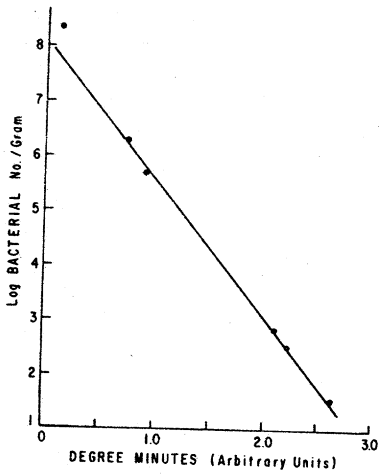

FIG. 5. *Log of bacterial number versus total heat treatment (degree-minutes—in arbitrary units) for frankfurters made from high-bacteriological-count raw materials.*

TABLE 3. *Influence of incubation temperature and presence of nitrite on the survival and growth of salmonellae and total non-salmonella flora in raw frankfurter emulsion*

Description of emulsion	Temperature of incubation, °C	No. of organisms ($\times 10^5$)	
		Zero time	24 h
S. dublin			
No nitrite	37	3.2	6.5
No nitrite	37	12	5.8
Nitrite	37	5	22
Nitrite	37	18	32
S. senftenberg 775W			
No nitrite	5	8	0.88
Nitrite	5	8	0.63
No nitrite	37	8	28
Nitrite	37	8	13
Total non-salmonella flora			
Nitrite	5	1.4	2
Nitrite	20	1.4	2,400
Nitrite	37	1.4	6,000

frankfurters indicated that very low numbers of bacteria survive the heating step. Yet, frankfurters spoil. A question was then posed: Can the bacteria which survive the heating step increase in number during subsequent low temperature storage and ultimately cause spoilage? Unpeeled frankfurters were stored in plastic bags at 5 C and examined bacteriologically at intervals. This method of storing frankfurters was chosen to eliminate the possible introduction of potential spoilage bacteria during peeling, handling, and packaging. The storage data (Table 4) indicated that the increase in count during storage is essentially due to growth of bacteria on the surface of the frankfurter. Since the frankfurters were not peeled until analysis, the bacteria/yeast counted should represent only those which survived the process and grew. The yeast probably was present in very low numbers after processing and only after 14 days of storage grew out and became the dominant flora.

DISCUSSION

Heating and smoking of raw emulsion during frankfurter processing serves several functions: (i) sets the emulsion and forms the skin of skinless frankfurters, (ii) kills the trichinae, (iii) accelerates cured meat color development, (iv)

TABLE 4. *Microorganisms developing in or on frankfurters during storage at 5 C*

Determination	Days of storage	Viable count (per g)	Predominant flora
Our frankfurters processed to 73.9 C			
Storage A			
Total[a]	0	9.6×10^2	Micrococci
Total[a]	7	5.1×10^2	Micrococci
Total[a]	14	5.0×10^2	Micrococci
Total[a]	21	9.0×10^4	Micrococci
Surface[b]	0	5	
Surface[b]	21	7.5×10^4	Micrococci
Storage B			
Total	0	8.9×10^2	Micrococci
Total	7	5.6×10^2	Micrococci
Total	14	1.6×10^5	Yeast
Frankfurters prepared from commercial emulsion in our pilot plant and processed to 73.9 C			
Total	0	1.2×10^2	Micrococci
Total	7	1.0×10^2	Micrococci
Total	14	3.4×10^3	Micrococci
Commercially processed frankfurters			
Total	0	2.6×10^2	Gram-positive, sporeforming rods
Total	14	6.0×10^4	Gram-positive, sporeforming rods

[a] A 50-g amount of frankfurter was blended for 1 min and plated as described in Materials and Methods.

[b] Surface of 50 g; 1.33 whole frankfurters were suspended in 200 ml of peptone water and shaken for 3 min; dilutions of this were then pour-plated as described in Materials and Methods.

imparts a desirable smoky flavor to the frankfurters, and (v) decreases the bacterial content of the frankfurters. The first function required a heating schedule as given above. The other functions occur simultaneously with the first. In terms of shelf life extension (keeping quality) and public health, the last function is perhaps the most important for the finished product. The normal heating given frankfurters both destroyed the salmonellae and reduced the total flora. Thus, the product was made safe from a public health view and the shelf life should be extended.

Because of the uniquely high heat resistance of *S. senftenberg* 775W (11, 16), our results can be extended to include all known serotypes. Thus, any processor following a heating schedule similar to ours for cooking frankfurters to 71.1 C internal temperature should produce salmonella-free frankfurters. Our data support the observation (14, 15) that salmonellae are not associated with processed frankfurters and form the basis of our conclusion: salmonellae do not survive the heating step of the frankfurter process. The presence of salmonellae in finished frankfurters would indicate either underprocessing or recontamination after processing. Whether our data for salmonellae in frankfurters can be extended to include other processed meat products is not known, but they should at least include bolognas, which are similar in composition and processing schedule to frankfurters, as well as other luncheon meats.

Our data also indicate that heat resistance of salmonellae is not dependent upon the method of contaminating the emulsion (bag versus cutter method). Incorporation of the organism into the emulsion (Fig. 2b) offered no protection to the salmonellae during the heating. Bayne (3), in his study of the heat resistance of *S. typhimurium* in ground chicken, found that the organism suspended in emulsified fat was destroyed as readily as when it was suspended in meat; our data for *S. senftenberg* 775W support this.

Bayne et al. (4) found that the heat resistance of salmonella in ground chicken muscle was similar to its heat resistance in other foods. Thus, heat resistance is not product dependent. Beloian and Schlosser (5) found for various baked foods that heating to 71.1 C (thermocouple in the slowest heating region of the food) was sufficient to destroy *S. senftenberg* 775W added to these foods. Dawson (6), in reviewing thermal destruction of salmonellae and other pathogens in turkey rolls and other meats, recommended an internal temperature of 71.1 C (at the coldest point) for destruction of low levels of pathogens in these products.

The inability of *S. dublin* and *S. senftenberg* 775W to grow in raw frankfurter emulsion (Table 4) is in contrast to an observation of Jensen (9) for *S. aerotrycke* (*S. typhimurium*). He observed that *S. aerotrycke* had a 4-h lag in stuffed, raw frankfurters incubated at 28.9 C. Since he presented no actual data, the extent of growth can not be ascertained. The cause for the difference between our work and that of Jensen is not known; it could be related to differences between strains of salmonellae, differences in preparation of emulsion, etc. He observed no lag with the total aerobic bacteria incubated at 28.9 C.

Our experiment with raw emulsion having a high initial bacterial count showed that the heating step of the frankfurter process can decrease bacterial numbers by 7-log cycles when the predominant flora was gram-negative rods (pseudomonad types). Whether the heating step could cause a similar decrease if the flora was completely micrococci or gram-positive, nonsporeforming rods is not known. However, these types might not be expected in meat held at 5 C for 6 days. Warnecke et al. (13) found at least a 3- to 6-log decrease in counts of viable bacteria in bologna processed to an internal temperature of 68 C. They did not list the types of bacteria found in the raw emulsion or the finished bolognas, but judging from the amount of kill observed in their experiment, the starting flora was probably gram-negative rods.

Examination of the bacteria surviving the heating step of our process indicated an almost exclusive flora of micrococci. Upon storage at 5 C, these survivors increased in number. Although our frankfurters held unpeeled for up to 21 days showed no signs of spoilage (slime formation, off odor, discoloration), micrococci have been shown to cause spoilage in packaged frankfurters (2). Probably, however, they would have spoiled the product after further storage. Our studies indicated that bacteria which survive the heating step can grow at 5 C and ultimately could cause spoilage. The yeast probably survived in such low numbers as to be undetectable immediately after processing. However, after destruction of the competing flora and in the selective environment between the frankfurter skin and the casing, certain numbers of the surviving flora can grow and cause spoilage.

Further support for bacteria surviving the heating step as the causative agent for spoilage comes from the observation that, for frankfurt-

ers stored 21 days, the surface count is very close to the total count (Table 4). At zero time, the surface of a frankfurter was almost sterile (<5 organisms/g). The selective environment of the casing permitted extensive growth of certain surviving organisms.

When frankfurters made from high-bacterial-count raw emulsion were stored unpeeled at 5 C, the flora and count increase were similar to frankfurters made from normal count emulsion. Thus, initial count of emulsion apparently had no effect on the keeping quality of the finished frankfurters.

One of the most important functions of the heating step of the frankfurter process appears to be destruction of any salmonellae present and reduction of the total bacterial count. Heating of the frankfurters during normal processing to an internal temperature of 71.1 C provided at least a 2.8 C (5 F) margin of safety for destruction of salmonellae and reduced substantially the total bacterial count. This recommended final temperature of 160 F (71.1 C) for frankfurters is commensurate with the final processing temperatures of 68 to 72 C (154 to 162 F) used in commercial practice (10). The heating step destroyed very large numbers of gram-negative rods when they were present in the raw emulsion. Variation in the numbers of salmonellae and total flora that survived at different temperatures was explained by calculating exposure to temperatures above 110 F (43.3 C) on the basis of degree-minutes. Plots of degree-minutes (in arbitrary units) versus log survivors gave straight lines. The predominant organisms surviving the heating step were micrococci which, in our experiments, increased to substantial numbers on the product during storage at 5 C.

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